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PROGRESS REPORT ON FIRE DETECTION RESEARCH IN THE UNITED STATES

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Introduction

Opportunities exist for new concepts in automatic fire detection that do a better job of discriminating a threatening fire from a non-threatening condition across the spectrum of applications. These opportunities arise because of a number of factors, including an increased need to protect more complex and variable structures, the need to replace an aging generation of smoke detectors, the need for detection systems to respond more quickly in tandem with less efficient halon replacement fire suppression systems, and the desire to better safeguard the public and meet evolving regulations. A technological push is being provided by new sensor technologies, by more sophisticated signal processing software, and by a greater understanding of fire physics and improved prediction capability for smoke movement. Competition from new technologies introduced internationally provides additional prodding for the U.S. industry to become fully aware of opportunities to enter new market areas and exploit advances in related technologies and scientific disciplines.

An assessment of advanced fire detection technologies, up to the time of the previous UJNR meeting, was made by Grosshandler [1]. That review sets the stage for what has transpired since. The results of much of the recent research from U.S. organizations can be found in the *Proceedings of the Fourth International Symposium on Fire Safety Science,* and in the proceedings of *Automatische Brandentdeckung (AUBE) '95.* In the case of the former publication, only seven of the more than 100 papers deal directly with the issue of fire detection. The latter publication is devoted entirely to the topic, but fewer than 10% of the articles were contributed by U.S. researchers. This relatively small output motivated BFRL to organize a workshop [2] on the subject of fire detector research in hopes of stimulating more U.S. activities.

NIST Workshop

The objective of the workshop was to identify the needs of users and specifiers of fire detection systems which are not currently being met by the U.S. fire protection industry; to highlight future needs which may result from new developments in the construction, transportation, and manufacturing sectors, or from regulatory changes; to identify generic, technological barriers which may limit the U.S fire protection industry from fully meeting the users' needs; and to develop a research agenda and recommend priorities to enable U.S. industry to overcome these technological barriers. A series of experts from industry, government, certifying organizations and academia were invited to review the various applications for fire detection systems and to discuss recent developments that could impact the future of the industry. The speakers were divided into focused panels of users and specifiers, systems and components manufacturers, regulators and certifiers, and researchers. Small working groups were convened after the panel discussions to identify critical research issues, concentrating on sensors, signal processing, systems integration and regulations.

The ultimate goals of a comprehensive and integrated research program were identified and include a lower ratio of false-positive-to-actual-fire indications, pre-fire warning for protection of high value operations, more fool-proof installation and maintenance methods, component compatibility for

system upgrade, a wider range of fires detectable, reliable detection of noxious fire precursors, faster and more precise response of fire detection systems customized to particular processes, earlier warning in connection with halon-alternative suppression systems, situation monitoring following automatic suppression, means to evaluate system trade-offs with the advent of performance-based standards, combination gas sensors for fire/environmental monitoring, and the capability for partial integration of fire detection with other building control functions. Technological barriers which might inhibit attainment of these goals and a research plan to enable the barriers to be breached were discussed. The proceedings of the workshop are available from NIST [2].

Fire Signatures

Measurements of the chemical and physical emissions from small fires are being taken at BFRL to develop a database of standard fire signatures. The intent is to eventually catalogue the major gases, particulates, and electromagnetic radiation emitted very early in a fire as means to develop new fire sensing strategies and certification procedures. In addition, the time varying temperature and velocity fields above these small fires are being probed. The initial study has been limited to smoldering cotton and pyrolyzing wood [3]. Future work will move on to flaming liquids and solids. Additional details are provided in the paper by Grosshandler presented elsewhere in these proceedings.

The Consumer Product Safety Commission and the U.S. Fire Administration sponsored research at BFRL to identify the conditions which exist on and above a residential kitchen cooking surface just prior to ignition of different foods [4]. The objective was to determine the feasibility of installing a sensor (or multiple sensors) on the stove which could interrupt power before ignition occurred, while being mindful of the need not to interrupt normal cooking operations. Temperature, velocity, gas concentration and smoke attenuation were recorded as bacon, soy bean oil, and sugar were heated to flaming conditions. No definitive conclusions have yet been drawn, and the work is continuing.

Milke [5] conducted bench-top and full-scale room experiments to identify major constituents formed early in small fires, and the response of existing detectors to them. He examined both flaming and non-flaming conditions, and also recorded the response of sensors to non-fire stimuli. Included in the study were over a dozen possible environmental sources likely to confound a fire detector. A paper describing this research can be found in these proceedings.

Goedeke and Gross [6] were concerned with sources of false alarms due to non-fire electromagnetic radiation present in aircraft hangars. They measured the spectral radiation from small pools of jet fuel and noted the fluctuation frequencies. Their investigation identified numerous potential sources of ultraviolet and infrared radiation (other than a fire) that, if modulated and in close enough proximity, could fool optical detectors into an alarm mode.

Fire Sensors

Thermal: There have been a number of different studies on new ways to sense the heat from a fire which could lead to detection systems that are more responsive and discriminatory. Latimer et al. [7] evaluated the ability of a thin-film heat flux gauge to sense a fire. By placing two micro-sensors side by side, each with a different absorptivity, they attempted to separate the radiative and convective contributions of heat flux, and to use this information to increase system selectivity. Sivathanu and Gore [8] proposed to make use of the radiation reflected from the surroundings to detect a fire located out of the direct line of sight of the sensor. Two silicon diode photo-detectors were used, one employing a narrow-band filter at 900 nm and the other a narrow-band filter at 1000 nm. By ratioing the voltages and analyzing the time varying fluctuations, they are able to measure the approximate temperature of the infrared source and to discriminate an out-of-direct-sight fire from a warm background object. Bakkom et al. [9] placed cards painted with thermochromic liquid crystals close to the ceiling of a half-scale room to demonstrate that a thermal plume indicative of a fire could be located quickly and remotely with a low resolution video camera.

Gas: There is a great deal of research currently underway in the U.S. on new gas sensing

technologies. In a workshop held at NIST [10], a number of techniques were mentioned that might be adaptable to early fire detection. Conductometric microsensor arrays are particularly attractive because a large number can be etched into a single silicon wafer, with each sensor doped differently. The substrate temperature can be programmed to minimize power consumption, to increase selectivity, or even to bake off surface contaminants [10 and 2, pp. 13-17].

Aerodyne Research, Inc. [11] has recently completed an assessment of a smart infrared fire detection system which focused on CO emission. By comparing performance trade-offs in optical component size and system sensitivity, they hoped to show that a practical and economical remote CO detection system was feasible. They concluded that the current state-of-technology is insufficient to render such a device competitive in the marketplace. On the other hand, Advanced Fuel Research [12 and 13] is continuing their efforts to devise a Fourier-transform infrared spectrometer for use in detecting a range of combustion gases and particulates in building fires. They plan to overcome some of the price and operational issues through clever software development and the selection of appropriate but less expensive components.

Smoke: The Consumer Product Safety Commission surveyed home owners with smoke detectors to ascertain the state of detector operability among the general U.S. public [14]. In a second CPSC study [15], interviews were held with fire investigators to determine how well smoke detectors performed in situations where an actual fire had occurred. The remains of the detectors were examined in an attempt to pin-point causes in cases where no detector-initiated alarm was sounded.

Aggarwal and Motevalli [16] measured the response of smoke detectors located on the ceiling of a 1.8 m high enclosure in an attempt to discriminate the smoke produced among different fuel sources. Scattered light, ionization, and obscuration methods were used to sense the smoke, while wood material, natural fabrics, different plastics, cooking oil and bread were used as fuels. An analysis based upon the Mie theory suggested that the response of the detectors is in fact fuel dependent, but that more precise measurements are necessary to reduce ambiguity.

Hughes Associates, Inc. [17], added a CO sensor to conventional smoke detectors to increase sensitivity and reduce the number of false alarms. Their evaluation program included measuring the response of the combination detector to a range of fire and non-fire sources of gases and particulates. They were encouraged by their ability to establish correlations between CO levels and ionization response, and to discriminate fire from non-fire events.

Field models have proven useful in guiding the selection of smoke detector sites on ceilings that are not flat. Forney et al. [18] demonstrated (numerically) how beams of various depth and spacing influence the movement of smoke, and the likely consequence of this altered flow on the time required for a smoke detector to alarm. Davis et al. [19] extended this work to include sloped ceilings and other geometrical complexities. Notarianni and Davis [20] examined the impact of high ceiling heights and cross-flows on smoke movement to a detector. They compared predictions of time-to-alarm using a field model to zone models and other less rigorous methods of analysis.

Detection Algorithms

Advances also have taken place in the U.S. in the development of signal processing and decision-making algorithms. Smith [21] examined the principle function of a fire detection system, and suggested that an economical basis for installing multiple sensors must lie in the quantity and quality (i.e., value) of the information provided. Knowledge Industries [22] received an SBIR grant from NIST to explore decision-theoretic methods for minimizing false alarms in residential fire detection. This method had been used successfully in the past for integrating complex, multiple sensory information such as that associated with real-time space vehicle control, and medical condition diagnosis. A belief network relating the levels of measured CO, CO_2, tin oxide sensor voltage, and room temperature to the probability of a fire was constructed, and the functionality of the method was demonstrated. An alternative approach to sensor data fusion for fire detection is currently being conducted by Opto-Knowledge Systems, Inc. [23]

Neural networks were utilized to train gas and smoke sensors in experiments by Milke [5] to

increase the rate of successfully classifying flaming fires, smoldering fires, and nuisance signals. This work is summarized in the current UJNR proceedings.

An algorithm was developed by Richards et al. [24] to solve an inverse heat transfer problem. The time-varying temperature distribution was known from measurements at several positions within a room, and the location and source of the heat (i.e. the fire) was sought. The model was able to predict within one to three minutes (depending upon the fire size) the location of the fire within one meter, but the heat release rate of the fire could only be predicted within a factor of five.

A computer simulation of photons emanating from a small fire and interacting with walls and participating media is being undertaken by Sivathanu and Gore [8]. The objective of their research is to determine the feasibility of determining explicitly the spectral radiative intensity on a near-infrared temperature sensor. This theoretical work is complimented by experiments described above.

Fire Detection in Aircraft Hangars

The U.S. Navy sponsored a series of tests to evaluate the performance of heat, smoke and radiation detectors used to protect aircraft hangars. Other branches of the Defense Department, NIST and five U.S. industry groups participated. Measurements of plume temperature, fuel mass loss, and wind speed were taken in actual aircraft hangars fires. Pools of jet fuel, 0.3 m to 4.6 m across, released heat at rates estimated to be between 100 kW and 40 MW. In addition to pool size, the researchers varied fuel type, ventilation conditions, and ambient temperature. Of particular interest were the effects of hangar ceiling height (15 m and 22 m) and geometry (e.g., draft curtains, cross-beams, and slope). Extensive data were compiled and are available in the final report [25]. A summary of the results with key findings regarding detector spacing, threshold fire size and the impact of draft curtains on time to activation are given in the article by Notarianni et al. [26]

Fire-emulator/detector-evaluator

The concept of a universal fire-emulator/detector-evaluator (FE/DE) was presented by Grosshandler [27]. The emulator portion of the FE/DE would produce a well controlled environment to simulate the atmosphere anywhere in or adjacent to a room that contains a growing fire. The signatures identified from standard fire tests would act as input to a computer simulation of flow within the room. Detector evaluation would be accomplished by inserting the sensing device into the FE/DE, which would be programmed to reproduce the environment at the detector as predicted from the flow model. The detector evaluator will have the capability to assess the performance of multi-sensor and line detectors. Progress on the construction of the FE/DE at NIST is included in another paper by the author compiled in these proceedings.

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Discussion

James Bold (??): Point of clarification, in the European Wood Fire Test, they have one test for flaming, one for smoldering. How do they control that fire in order to reproducibly produce smoldering without converting to flaming?

William Grosshandler: The smoldering fire is identical to the one we were testing, and we were very pleased to find that it is highly reproducible based upon their description of the machine.

James Bold: However, I would expect a significant variation from one laboratory to another because they only specify a temperature on the hot plate. So it's possible that there will be variation from laboratory to laboratory.